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Development of an Improved Ballistic Acceptance Test for High Hard Armor Steel Plate - MIL-A-46100

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This report is one of three reports generated as a subtask under the project entitled "Development of Improved High Hard Armor Steel (MIL-A-46100)" funded by the PM, Survivability (TACOM). This report investigates ballistic acceptance tests for MIL-A-46100 plate. Ballistic test results for MIL-A-46100 armor plate with the 20mm M602 projectile show a high level of scatter in V_{50} values. The V_{50} is used as the criterion for acceptance/ rejection of MIL-A-46100 armor plate. Furthermore, the M602 projectile produces a shatter gap phenomenon when tested verses high hardness plate near the 1.1 inch thickness. The shatter gap results in two V_{50} values with a spread of approximately 180 - 200 ft./sec.. Reasons for the high failure rate of 20% for MIL-A-46100 plate can, in part, be attributed to a combination of shatter gap phenomenon and scatter in V_{50} measurements. ARL/MD heats of MIL-A-46100 armor plate were processed and tested with the 20mm M602 projectile and a 1/2 scale 30mm APDS tungsten projectile. Results of ballistic testing show that the 1/2 scale 30mm APDS projectile exhibits minimal scatter in V_{50} values with no shatter gap and therefore is considered to be a superior round for testing and qualifying MIL-A-46100 steel armor.

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Objective

The objective of this portion of the Improved High Hard Steel Program is to investigate the ballistic acceptance test in MIL-A-46100 and to improve ballistic acceptance test methods for armor plate thicknesses greater than 0.725 inches. This effort focused on ballistic acceptance testing methodology. Metallurgical and processing aspects of MIL-A-46100 high hardness steel was also investigated and will be reviewed in a future report for this project. The objective of this combined effort is to insure consistent ballistic performance of this steel armor plate and to achieve the goal of a plate acceptance level greater than 95%.

Introduction

This report is one of three reports on "Development of Improved High Hard Armor Steel (MIL-A-46100) Program" funded by the PM, Survivability (TACOM). The focus of this report is to investigate the ballistic acceptance requirements of MIL-A-46100 and the testing methodology.

The current ballistic test requirements for High Hard armor plate in MIL-A-46100 are shown in Table 1. From ballistic failure rates detailed in previous investigations (references 1 and 2), it can be concluded that little or no problem is encountered in meeting the minimum ballistic requirements for plate less than 0.876 inches thick or greater than 1.486 inches thick. However, MIL-A-46100 plate with thicknesses between 0.876 and 1.486 suffers ballistic rejection rates of 20%. This effort, therefore, concentrated on issues related to: 1) thicknesses greater than 0.876 inches and less than 1.486; 2) current projectiles (14.5mm API BS41 and 20mm API-T M602) used for testing these thicknesses as per MIL-A-46100; and 3) a candidate test projectile to replace the BS-41 and M602 tungsten-carbide core projectiles.

Background

An examination of the test projectiles used in MIL-A-46100 (Table 1) shows that for low failure rate material (thickness range of 0.125 inches to 0.765 inches), the 0.30 Cal AP M2, 0.50 Cal AP M2, and 14.5mm API B32 projectiles are specified. The core or penetrator material for these projectiles is hard steel (HRC61-66); furthermore, plate impact is conducted at 30° obliquity. For armor plate greater than 0.765 inch thick, the penetrator material for the specific test projectile (14.5mm BS41 and 20mm M602) is cemented tungsten-carbide (WC). The use of this ultra high-hardness brittle penetrator material can lead to a large variation in plate V_{50} ballistic limit. The brittle properties of the tungsten carbide core material lead to premature fracture upon impact which in turn result in inconsistent V_{50} values. In some cases a shatter gap could exist. Shatter gap is a condition where the same armor plate will have two V_{50} ballistic limits, with differences greater than the 150 ft/sec spread allowed in determining the V_{50}. Shatter gap occurs because the projectile core (in this case, tungsten carbide) may or may not shatter (break up) upon impact. Shattering of the core is not consistent and is a function of impact velocity of the projectile, hardness of the plate, makeup of the plate (chemistry, processing, etc.) and also thickness of the plate with respect to the diameter of the projectile.

Another factor that could be contributing to high failure rate is the 0° obliquity impact requirement for testing with the 20mm API-T M602 projectile. It has been noted that testing at 0° obliquity increases the propensity for steel armor plate to fail in adiabatic shear upon impact by the projectile. This shearing process results in the formation of a plug of diameter approximately equal to that of the penetrator and ejection of the plug from the armor plate, thereby, reducing plate resistance to penetration.

The problem presented by tungsten carbide test projectiles, shatter gap and adiabatic shear, although noted previously by many investigators, has not been addressed or documented in a manner which could alleviate the problem of high ballistic failure rates for MIL-A-46100 material. That is the purpose of this work.

Procedure

The investigation was divided into three Phases. Phase I will deal with the results of changing the impact obliquity. Phase II will deal with changing the test projectile utilizing ARL/MD produced plates and Phase III will investigate the test projectile used in Phase II against plates produced by Lukens Steel.

PHASE I

It was originally thought that the high failure rate of MIL-A-46100 armor plate at a thickness of approximately 1.1 inches could be reduced if the ballistic acceptance test was modified only slightly. By changing the obliquity angle from 0° to 30° for the 20mm M602 projectile, it was believed that increase in line-of-sight thickness would eliminate the high level of scatter and shatter gap phenomena that was occurring in the plate thickness area of 1.1 inches. Thicker plate was not exhibiting this high level of scatter and failure. At 30° obliquity the line of sight thickness is increased by 15.5%.

Phase I ballistic testing at both 0° and 30° obliquity was performed on thirty-eight (38) high hardness plates by Combat Systems Test Activity (CSTA) at APG. These plates, ranging from 0.862" to 1.598" in thickness, were produced by Lukens Steel per MIL-A-46100. The majority of the plates were near the critical 1.1" thickness value. The first eight (8) plates listed in Table 3 (thickness less than 1.066 inches) were first tested with the 14.5mm API BS41 Projectile at 30° obliquity as required by MIL-A-46100. All thirty-eight (38) plates were then tested against the 20mm M602 projectile at the proposed 30° obliquity angle (see Table 2 for proposed change in requirements). Test results are reviewed in the Discussion Section of this Report.

PHASE II

Phase II ballistic testing explored the notion of changing the test projectile and compare the results obtained with a 1/2 scale 30mm APDS tungsten projectile and the 20mm M602 projectile. Fifteen (15) high hardness plates were ballistically tested at 0° obliquity against both projectiles. Heats produced by ARL/MD were processed to produce plates close to 1.1" in thickness. A nominal chemical composition, as shown below , for MIL-A-46100 material was used. The nominal composition was determined by averaging the composition of acceptable plates from reference 2.

Carbon -	0.30 %	Chromium -	0.55 %
Manganese -	0.90 %	Molybdenum -	0.55 %
Silicon -	0.42 %	Phosphorus -	0.011 %
Nickel -	1.05 %	Sulfur -	0.002 %

PHASE III

Phase III ballistic testing expanded on Phase II and included further tests with steel plate produced by Lukens Steel per MIL-A-46100. Seven plates (12"x36") were cut into 12"x12" plates and ballistically tested versus the 1/2 scale 30mm APDS and the 20mm M602 projectiles at 0° obliquity. A select number of the 12"x12" plates were re-heat treated and/or reprocessed to the 1.1" thick plate.

Discussion

PHASE I

Results of Phase I ballistic testing revealed that V_{50} values for the 20mm M602 projectile at 30° obliquity are no more consistent than those obtained at 0° obliquity. Test results are summarized in Table 3 and displayed in Figure 1. These results are taken from Reference 3. It is readily observed that the scatter in the M602 data, based on the variance from the least squares curve fit, is greater for the proposed 30° impact condition than the current requirement of 0°. The failure rate for these thirty-eight plates at 30° obliquity was calculated to be 23.7%. Based on these results, it was decided to pursue a replacement for the 20mm M602 and 14.5mm API BS41 tungsten carbide projectiles, for material of thicknesses 0.876" to 1.485".

Following a review of the literature and historical data base for steel and tungsten carbide core projectiles, it was determined that a tungsten core projectile could satisfy the ballistic acceptance testing requirements for high hardness steel armor plate. The 1/2 scale 30mm APDS tungsten penetrator was selected as the candidate test projectile. Available tungsten rounds, such as, the 25mm APDS projectile, were also considered. For this latter projectile, the V_{50} values for the material in the thickness range of interest would be well below practical launcher velocities. At these low velocities it would be difficult to control both strike velocity and projectile yaw, test parameters important to development of a practical and reproducible ballistic acceptance test.

PHASE II

Feasibility of using the 1/2 scale 30mm APDS penetrator required ballistic testing of high hardness steel plates across the thickness range of 0.876" to 1.485". These plates were produced by ARL/MD and processed to the required thickness and hardness levels. Ballistic testing focused on the critical thickness of 1.1", plate thickness of highest failure rate, as determined from ARL-TR-218. Processing and heat treating parameters used for all the ARL/MD heats is given in Appendix A.

Test results versus the 1/2 Scale 30mm and the 20mm M602 projectile are listed in Tables 4A, 4B, 5A, 5B, 6A and 6B. It is readily apparent that the 1/2 scale 30mm yields very consistent V_{50} ballistic impact values. However, the ARL/MD produced plates also showed consistent V_{50} values with the 20mm M602 projectile. Heat Z-70B-8 was produced to determine whether ARL/MD produced plates indeed meet the current ballistic requirement of MIL-A-46100 across a wider thickness range then shown in Tables 4A, 5A, and 6A. (see Table 7). The results obtained show ARL/MD material meets ballistic specification requirements.

Further ballistic testing was required to show any advantage in changing test projectile. The armor plates originally tested at CSTA (Table 3) were re-tested at ARL/MD with the 20mm M602 projectile at 0° obliquity (see Table 8) and with the 1/2 scale 30mm APDS Projectile (see Table 10). Careful ballistic testing of these plates (Lukens material) with the 20mm M602 projectile resulted in multiple V_{50} values (shatter gap phenomena). However, this was not the case with ARL/MD heats (Z-70B-1,2,7,and 8) for which singular V_{50} values were obtained (Tables 4A, 5A, 6A and 7). Only when ARL/MD heats provided plate with high carbon content (>0.31%) was a shatter gap observed (see Table 9). When all plates, both ARL/MD and Lukens produced, were tested with the 1/2 scale 30mm APDS projectile, results proved consistent (see Tables 10 & 11). The results were provided to CSTA and subsequently modeled for an initial acceptance requirement for the 1/2 scale 30mm APDS projectile (see Figure 3). This acceptance curve will be used for comparisons only; the final acceptance requirement (model) that will be used in the specification will be developed by CSTA at the conclusion of this effort.

PHASE III

The results of Phase III are summarized in Tables 12A - 12G. Lukens plates designated 'as is' were tested at CSTA. Additional plates (12"x 36") from the same lot (and, therefore, from the same heat) were provided by Lukens to ARL/MD and were tested by ARL/MD in the following conditions: 1) 'as received'; 2) 're-heat treated' (see Appendix A for parameters); and 3) 'rolled to 1.1 inch'. The results show that in some cases the 'as received' plates failed the 20mm M602 requirement when its' counter part 'as is' plate passed the requirement. One of these plates had a shatter gap. Plates that were 're-heat treated' passed all the ballistic requirements. All the plates that were 'rolled to 1.1' failed the 20mm M602 ballistic requirement and one plate also had a shatter gap. For all the plates that were tested 'as received' or 'rolled to 1.1' with the 1/2 scale 30mm projectile all but one plate passed the proposed ballistic limit (note that the acceptance requirements for the 1/2 scale 30mm APDS projectile, as mentioned, is not the final). The final requirement that will be included in the specification (MIL-A-46100) is to be generated by CSTA at a later date.

To demonstrate the consistency of data obtained with the 1/2 scale 30mm APDS projectile as compared to the 20mm M602 Projectile all the data generated for this effort was plotted in Figure 3. The acceptance requirements for both projectiles are also shown in Figure 3 so that one can graphically see the difference in requirements. Failure rates decrease markedly for the tungsten test projectile when compared with the tungsten-carbide core projectile. Although this effort did not investigate the 14.5mm API BS41 Projectile, it is believed that the same problems exists with this round. A review of the data base generated from reference 2 indicates a higher than normal failure rate for the 14.5mm API BS41 Projectile; also there are examples of what are believed to be a shatter gap problem.

Conclusions

1. The 1/2 scale 30mm APDS tungsten projectile results in consistent V_{50} ballistic limit results with no shatter gap phenomena when tested against **all** variants of MIL-A-46100 armor plate (Lukens produced, ARL/MD produced, and reprocessed material).

2. A V_{50} shatter gap exists with industry produced plates and also with high carbon ARL/MD produced plates versus the 20mm M602 projectile (currently used in MIL-A-46100 for acceptance testing). This is illustrated in Figure 2.

3. A proposed ballistic test requirement matrix for MIL-A-46100 is provided in Table 13. Specifically, the 1/2 scale 30mm APDS tungsten projectile is recommended in lieu of the 14.5mm BS41 and the 20mm M602 tungsten carbide projectile in the critical thickness range of 0.876 to 1.485 inches.

Recommendations

1. Drawings for the 1/2 scale 30mm APDS Projectile (Figure 4) including the required sabot (Figure 5), etc. be provided by ARL/MD to CSTA to facilitate production of the round and begin testing plates (industry produced) to generate the ballistic requirements.

2. Contact Industry Representatives to provide plates of various thicknesses for ballistic testing at CSTA.

3. Develop V_{50} ballistic acceptance curves for the 1/2 scale 30mm APDS projectile in the thickness range of 0.876 to 1.485 inches. It should be noted that the thickness range for the 14.5mm API B32 Projectile was increased and therefore, CSTA will need to extend the ballistic acceptance tables for this round.

4. Modify the current MIL-A-46100 Specification by incorporating the new ballistic tables generated by CSTA (see Table 13).

5. Complete the over-all effort by utilizing remaining ARL/MD heats to provide guidelines to industry on chemistry and processing on MIL-A-46100 material.

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2. Grubinskas, R.C. and Squillacioti, R.J., The Development of an Automated Armor Data Base - Phase 1, U.S. Army Research Laboratory, ARL-TR-218, September 1993.

3. TECOM Project No. 1-EG-965-000-773, Armor Steel Ballistic Test, 20-MM API-T M602 Projectiles, dated 12 July 1993 by William H. Allison, Test Director.

TABLE 1

MIL SPEC MIL-A-46100 REVISIONS C AMD ^ & D TABLE OF REQUIRED ARMOR PLATE THICKNES ANGES AS A FUNCTION OF PROJECTILE CALIBER		
PROJECTILE [CALIBER]	OBLIQUITY [DEGREES]	THICKNESS RANGE [INCHES]
CAL 0.30 AP M2	30	0.125-0.315
CAL 0.50 AP M2	30	0.316-0.590
14.5mm API B32	30	0.591-0.765
14.5mm API BS41	30	0.766-1.065
20mm API-T M602	0	1.066-2.100

TABLE 2

MIL SPEC MIL-A-46100 PROPOSED BALLISTIC REQUIREMENTS		
PROJECTILE [CALIBER]	OBLIQUITY [DEGREES]	THICKNESS RANGE [INCHES]
CAL 0.30 AP M2	30	0.125-0.315
CAL 0.50 AP M2	30	0.316-0.590
14.5mm API B32	30	0.591-0.875
20mm API-T M602	30	0.876-1.485
20mm API-T M602	0	1.486-2.100

TABLE 3

RESULTS OF BALLISTIC TESTING							
HEAT #	FIRING RECORD NUMBER	THICK-NESS (INCH)	14.5mm BS41 at 30° OBLIQUITY V_{50} (FT/SEC)	EXCESS[a] (FT/SEC)	20mm M602 at 30° OBLIQUITY V_{50} (FT/SEC)	EXCESS[b] (FT/SEC)	ARL /MD #
R4806	92001490	0.862	2513	-9	2126	391	--
R9167	93000373	0.875	2618	66	1846	68	--
R4806	92001688	0.882	2586	17	2017	216	--
R4806	92001687	0.885	2591	15	1880	69	--
R9167	93000372	0.887	2618	37	2019	201	--
R7948	9200148[illegible]	0.992	2912	97	2288	154	--
R7455	92001192	1.005	2928	85	2224	54	8H
R9167	93000384	1.010	2928	74	2219	35	--
			20mm M602 at 0° OBLIQUITY				
R7138	92001131	1.114	1954	30	2604	152	XX
R5390	92001127	1.118	2018	87	2367	-95	6F
R8250	92001464	1.120	1967	33	2700	233	9I
R3650	92000495	1.120	2100	166	2617	150	4D
R8250	92001715	1.120	1967	33	2479	12	--
R8250	92001714	1.121	1787	-149	2508	39	11K
R8250	93000209	1.123	1998	59	2414	-60	2B
R8250	92001465	1.127	1832	-114	2445	-39	10J
R4806	92001713	1.127	2055	109	2520	36	--
R8424	93000207	1.127	2046	100	2414	-70	12L
R3650	92000494	1.134	1932	-25	2373	-128	3C

[a] Variance from ballistic requirement of MIL-A-46100D. Negative sign (-) indicates a failure.

[b] Variance from least square fit curve for the 38 plates tested at 30° obliquity. $BL = [1000 \times (12.472\ t - 7.399)^{1/2}] - 97$, where t = thickness. Negative sign (-) indicates a failure.

TABLE 3
(continued)

RESULTS OF BALLISTIC TESTING							
HEAT #	FIRING RECORD NUMBER	THICK-NESS (INCH)	20mm M602 at 0° OBLIQUITY V_{50} (FT/SEC)	EXCESS[a] (FT/SEC)	20mm M602 at 30° OBLIQUITY V_{50} (FT/SEC)	EXCESS[b] (FT/SEC)	ARL /MD #
R6348	92001006	1.140	1860	-108	2384	-131	5E
R6857	92001130	1.140	2055	87	2452	-63	7G
R8983	92001716	1.144	2033	59	2546	21	--
R8250	93000094	1.180	2209	176	2748	139	1A
R6430	92001134	1.242	2148	18	2945	197	--
R8250	92001734	1.249	2226	85	2952	188	--
R6857	92001005	1.249	2184	43	2922	158	--
R7138	92001135	1.250	2162	19	2893	127	--
R8424	93000211	1.253	2163	16	2818	46	--
	C	1.260	2084	-74	2781	-6	--
R7948	93000223	1.269	2365	194	3031	224	--
R7948	93000224	1.271	2272	98	3085	274	--
R4820	92000829	1.363	2277	-32	2838	-164	--
R4820	92000828	1.366	2287	-26	3002	-6	--
R7948	93000001	1.374	2418	93	3258	234	--
R4820	92001062	1.384	2461	122	3271	227	--
	A	1.390	2367	20	3317	261	--
	B	1.390	2270	-77	3175	119	--
R8250	93000095	1.598	2757	134	3797	353	--

[a] Variance from ballistic requirement of MIL-A-46100D. Negative sign (-) indicates a failure.

[b] Variance from least square fit curve for the 38 plates tested at 30° obliquity. $BL = [1000 \times (12.472\,t - 7.399)^{1/2}] - 97$, where t = thickness. Negative sign (-) indicates a failure.

TABLE 4A

BALLISTIC RESULTS FOR ARL/MD HEAT # Z-70B-1

20mm M602 at 0° OBLIQUITY					
PLATE ID #	TEST NO.	V_{50} (FT/SEC)	SPREAD (FT/SEC)	ACTUAL THICKNESS (INCH)	HARDNESS (RHC)
1	138-93	2079	110	1.122	48
3	137-93	1974	56	1.132	48
5	133-93	1983	53	1.119	48
7	136-93	2035	108	1.135	48

TABLE 4B

BALLISTIC RESULTS FOR ARL/MD HEAT # Z-70B-1

30mm 1/2 SCALE at 0° OBLIQUITY					
PLATE ID #	TEST NO.	V_{50} (FT/SEC)	SPREAD (FT/SEC)	ACTUAL THICKNESS (INCH)	HARDNESS (RHC)
2	T-54-93	3646	71	1.130	48
4	T-57-93	3683	77	1.124	52
6	T-63-93	3721	47	1.136	48
8	T-64-93	3783	126	1.139	48

TABLE 5A

BALLISTIC RESULTS FOR ARL/MD HEAT # Z-70B-2

20mm M602 at 0° OBLIQUITY					
PLATE ID #	TEST NO.	V_{50} (FT/SEC)	SPREAD (FT/SEC)	ACTUAL THICKNESS (INCH)	HARDNESS (RHC)
1	129-93	1992	114	1.120	48
3	128-93	1993	48	1.106	48
5	132-93	2011	68	1.131	48
7	131-93	2008	148	1.132	48
9	130-93	2011	77	1.137	48

TABLE 5B

BALLISTIC RESULTS FOR ARL/MD HEAT # Z-70B-2

30mm 1/2 SCALE at 0° OBLIQUITY					
PLATE ID #	TEST NO.	V_{50} (FT/SEC)	SPREAD (FT/SEC)	ACTUAL THICKNESS (INCH)	HARDNESS (RHC)
2	T-55-93	3687	45	1.126	48
4	T-68-93	3671	129	1.130	48
6	T-67-93	3749	67	1.143	48
8	T-66-93	3753	136	1.133	48
10	T-65-93	3721	122	1.132	48

TABLE 6A

BALLISTIC RESULTS FOR ARL/MD HEAT # Z-70B-7

20mm M602 at 0° OBLIQUITY					
PLATE ID #	TEST NO.	V_{50} (FT/SEC)	SPREAD (FT/SEC)	ACTUAL THICKNESS (INCH)	HARDNESS (RHC)
1	143-93	2020	124	1.126	52
3	142-93	2020	110	1.121	48
5	141-93	2034	87	1.118	48
7	140-93	2115	105	1.134	48

TABLE 6B

BALLISTIC RESULTS FOR ARL/MD HEAT # Z-70B-7

30mm 1/2 SCALE at 0° OBLIQUITY					
PLATE ID #	TEST NO.	V_{50} (FT/SEC)	SPREAD (FT/SEC)	ACTUAL THICKNESS (INCH)	HARDNESS (RHC)
2	T-56-93	3668	76	1.116	48
4	T-69-93	3776	112	1.149	48
6	T-70-93	3643	57	1.123	52
8	T-71-93	3682	96	1.119	52

TABLE 7

BALLISTIC RESULTS FOR ARL/MD HEAT # Z-70B-8

20mm M602 at 0° OBLIQUITY						
PLATE ID #	TEST NO.	V_{50} (FT/SEC)	SPREAD (FT/SEC)	REQ. V_{50}	ACTUAL THICKNESS (INCH)	HARDNESS (RHC)
1	152-93	2053	83	1927	1.116	48
2	155-93	2020	81	1968	1.140	48
3	156-93	1984	95	1927	1.116	48
4	157-93	1611	98	N/A	1.005	48
5	158-93	2147	60	2093	1.212	49.2
6	159-93	2325	49	2203	1.290	48
7	160-93	2439	64	2355	1.396	52
8	161-93	2552	103	2541	1.534	50.2

TABLE 8

ARL/MD BALLISTIC RESULTS FOR CSTA SHOT MATERIAL

20mm M602 at 0° OBLIQUITY						
PLATE ID #	TEST NO.	V_{50} (FT/SEC)	SPEC REQ. (FT/SEC)	ACTUAL THICKNESS (INCH)	HARD NESS (RHC)	CSTA's V_{50} (FT/SEC)
494	139-93	2068	1959	1.135	51.2	1932
1131	135-93	1907	1993	1.115	51.1	1954
1715	185-93	1749	1943	1.125	48.8	1967
0829	169-93	2119	2319	1.370	48.3	2277
1716	171-93	1928	1968	1.140	49.6	2033
1134	186-93	1966	2133	1.244	47.8	2148
0211	168-93	2130	2147	1.253	49.3	2163

NOTES: 1) Plate #1715 shows a potential for a shatter gap, however, there was not enough material to shoot and verify.

2) Plate #1134 had a 4 shot V_{50} of 2073 feet/sec.

3) Plate ID # is the last 4 digits of the CSTA firing record from Table 3.

TABLE 9

BALLISTIC RESULTS OF ARL/MD HEATS
20mm M602 at 0° OBLIQUITY

Z-70A					
PLATE ID #	TEST NO.	HIGH V_{50} (FT/SEC)	ACTUAL THICKNESS (INCH)	LOW V_{50} (FT/SEC)	HARDNESS (RHC)
7	164-93	1861	1.050	1778	52.5
8	163-93	1851	1.035	1744	52
9	162-93	1893	1.055	--	52
4	178-93	1921	1.043	--	51
6	180-93	1908	1.042	1793	51
5	181-93	1830	1.039	1739	49.4
Z-51H					
C	184-93	1928	1.076	--	49
A	173-93	1827	1.025	--	49

TABLE 10

ARL/MD BALLISTIC RESULTS FOR CSTA SHOT MATERIAL

30mm 1/2 SCALE at 0° OBLIQUITY					
PLATE ID #	TEST NO.	V_{50} (FT/SEC)	SPREAD (FT/SEC)	ACTUAL THICKNESS (INCH)	HARDNESS (RHC)
2B 0209	T61-93	3844	4	1.132	50
4D 0495	T59-93	3874	13	1.142	47
8H-1 1192	T60-93	3344	108	1.008	50
9I 1464	T62-93	3639	99	1.127	47
11K 1714	T58-93	3672	79	1.125	49

TABLE 11

BALLISTIC RESULTS OF ARL/MD HEATS
30mm 1/2 Scale at 0° OBLIQUITY

HEAT #	PLATE #	TEST #	V_{50} (FT/SEC)	THICKNESS (INCH)	HARDNESS (RHC)
Z-70A	1	T-1-94	3632	1.066	51.4
Z-70A	3	T-2-94	3431	1.068	53.4

TABLE 12A

BALLISTIC RESULTS FOR LUKENS STEEL PLATES

20mm M602 at 0° OBLIQUITY or 30mm 1/2 SCALE at 0° OBLIQUITY								
COMMENTS	HEAT #	PLATE #	SIZE ($INCH^2$)	THCK (INCH)	20mm V_{50} (FT/SEC)	30mm 1/2 V_{50} (FT/SEC)	ACCEPT V_{50} (FT/SEC)	P / F
AS IS	R6857	12B	12x36	1.140	2055	----	1968	P
AS RECEIVED	R6857	LA1	12x12	1.153	1876	----	1989	F
RE-HEAT TREATED	R6857	LA2	12x12	1.141	1996	----	1969	P
AS RECEIVED	R6857	LA3	12x12	1.141	----	3785	3649	P

TABLE 12B

BALLISTIC RESULTS FOR LUKENS STEEL PLATES

20mm M602 at 0° OBLIQUITY or 30mm 1/2 SCALE at 0° OBLIQUITY								
COMMENTS	HEAT #	PLATE #	SIZE ($INCH^2$)	THCK (INCH)	20mm V_{50} (FT/SEC)	30mm 1/2 V_{50} (FT/SEC)	ACCEPT V_{50} (FT/SEC)	P / F
AS IS	R7138	2AB	12x36	1.114	1954	----	1924	P
AS RECEIVED	R7138	LB1	12x12	1.124	1791 2003	----	1941	F P
RE-HEAT TREATED	R7138	LB2	12x12	1.123	1972	----	1939	P
AS RECEIVED	R7138	LB3	12x12	1.119	----	3692	3582	P

TABLE 12C

BALLISTIC RESULTS FOR LUKENS STEEL PLATES

20mm M602 at 0° OBLIQUITY or 30mm 1/2 SCALE at 0° OBLIQUITY								
COMMENTS	HEAT #	PLATE #	SIZE ($INCH^2$)	THCK (INCH)	20mm V_{50} (FT/SEC)	30mm 1/2 V_{50} (FT/SEC)	ACCEPT V_{50} (FT/SEC)	P / F
AS IS	R7138	1BB	12x36	1.250	2162	----	2143	P
AS RECEIVED	R7138	LC1	12x12	1.250	2180	----	2143	P
AS RECEIVED	R7138	LC2	12x12	1.249	----	4076	3959	P
AS RECEIVED	R7138	LC3	12x12	1.245	----	4087	3948	P

TABLE 12D

BALLISTIC RESULTS FOR LUKENS STEEL PLATES

20mm M602 at 0° OBLIQUITY or 30mm 1/2 SCALE at 0° OBLIQUITY								
COMMENTS	HEAT #	PLATE #	SIZE ($INCH^2$)	THCK (INCH)	20mm V_{50} (FT/SEC)	30mm 1/2 V_{50} (FT/SEC)	ACCEPT V_{50} (FT/SEC)	P / F
AS IS	C0917	7	12x36	1.258	2187	----	2155	P
AS RECEIVED	C0917	LD1	12x12	1.256	2189	----	2152	P
AS RECEIVED	C0917	LD2	12x12	1.260	----	4117	3989	P
AS RECEIVED	C0917	LD3	12x12	1.261	----	4245	3992	P

TABLE 12E

BALLISTIC RESULTS FOR LUKENS STEEL PLATES

20mm M602 at 0° OBLIQUITY or 30mm 1/2 SCALE at 0° OBLIQUITY								
COMMENTS	HEAT #	PLATE #	SIZE ($INCH^2$)	THCK (INCH)	20mm V_{50} (FT/SEC)	30mm 1/2 V_{50} (FT/SEC)	ACCEPT V_{50} (FT/SEC)	P / F
AS IS	C3750	2	12x36	1.233	2183	----	2116	P
ROLLED TO 1.1	C3750	LE1	12x12	1.032	1690 2077	----	1780	F P
ROLLED TO 1.1	C3750	LE2	12x12	1.092	1800	----	1886	F
ROLLED TO 1.1	C3750	LE3	12x12	1.086	----	3653	3480	P

TABLE 12F

BALLISTIC RESULTS FOR LUKENS STEEL PLATES

20mm M602 at 0° OBLIQUITY or 30mm 1/2 SCALE at 0° OBLIQUITY								
COMMENTS	HEAT #	PLATE #	SIZE ($INCH^2$)	THCK (INCH)	20mm V_{50} (FT/SEC)	30mm 1/2 V_{50} (FT/SEC)	ACCEPT V_{50} (FT/SEC)	P / F
AS IS	C0815	3A	12x36	1.378	2399	----	2330	P
ROLLED TO 1.1	C0815	LG1	12x12	1.089	1848	----	1883	F
ROLLED TO 1.1	C0815	LG2	12x12	1.090	----	3520	3493	P
AS RECEIVED	C0815	LG3	12x12	1.385	----	4424	4319	P

TABLE 12G

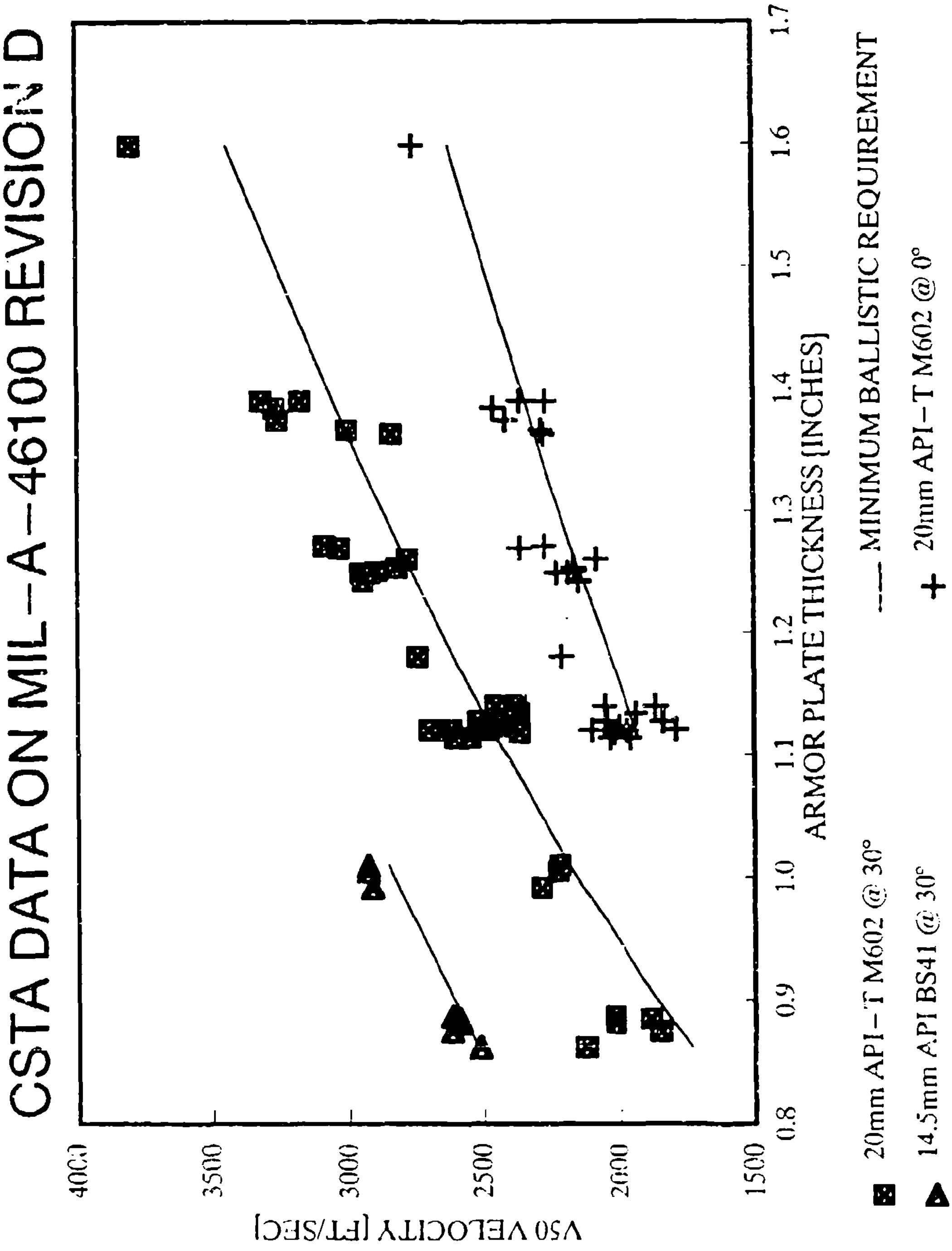
BALLISTIC RESULTS FOR LUKENS STEEL PLATES

20mm M602 at 0° OBLIQUITY or 30mm 1/2 SCALE at 0° OBLIQUITY								
COMMENTS	HEAT #	PLATE #	SIZE ($INCH^2$)	THCK (INCH)	20mm V_{50} (FT/SEC)	30mm 1/2 V_{50} (FT/SEC)	ACCEPT V_{50} (FT/SEC)	P / F
AS IS	C2029	3AA	12x36	1.373	2441	----	2330	P
ROLLED TO 1.1	C2029	LH1	12x12	1.091	1801	----	1885	F
ROLLED TO 1.1	C2029	LH2	12x12	1.082	----	3520	3468	P
AS RECEIVED	C2029	LH3	12x12	1.382	----	4280	4311	F

TABLE 13

PROPOSED BALLISTIC REQUIREMENTS FOR MIL-A-46100		
PROJECTILE [CALIBER]	OBLIQUITY [DEGREES]	THICKNESS RANGE [INCHES]
CAL 0.30 AP M2	30	0.125-0.315
CAL 0.50 AP M2	30	0.316-0.590
14.5mm API B32	30	0.591-0.875
1/2 SCALE 30mm APDS	0	0.876-1.485
20mm API-T M602	0	1.486-2.100

Figure 1



CSTA DATA ON MIL-A-46100 REVISION D
V50 VELOCITY [FT/SEC]
4000
3500
3000
2500
2000
1500
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
ARMOR PLATE THICKNESS [INCHES]
20mm API-T M602 @ 30°
14.5mm API BS41 @ 30°
MINIMUM BALLISTIC REQUIREMENT
20mm API-T M602 @ 0°

Figure 2

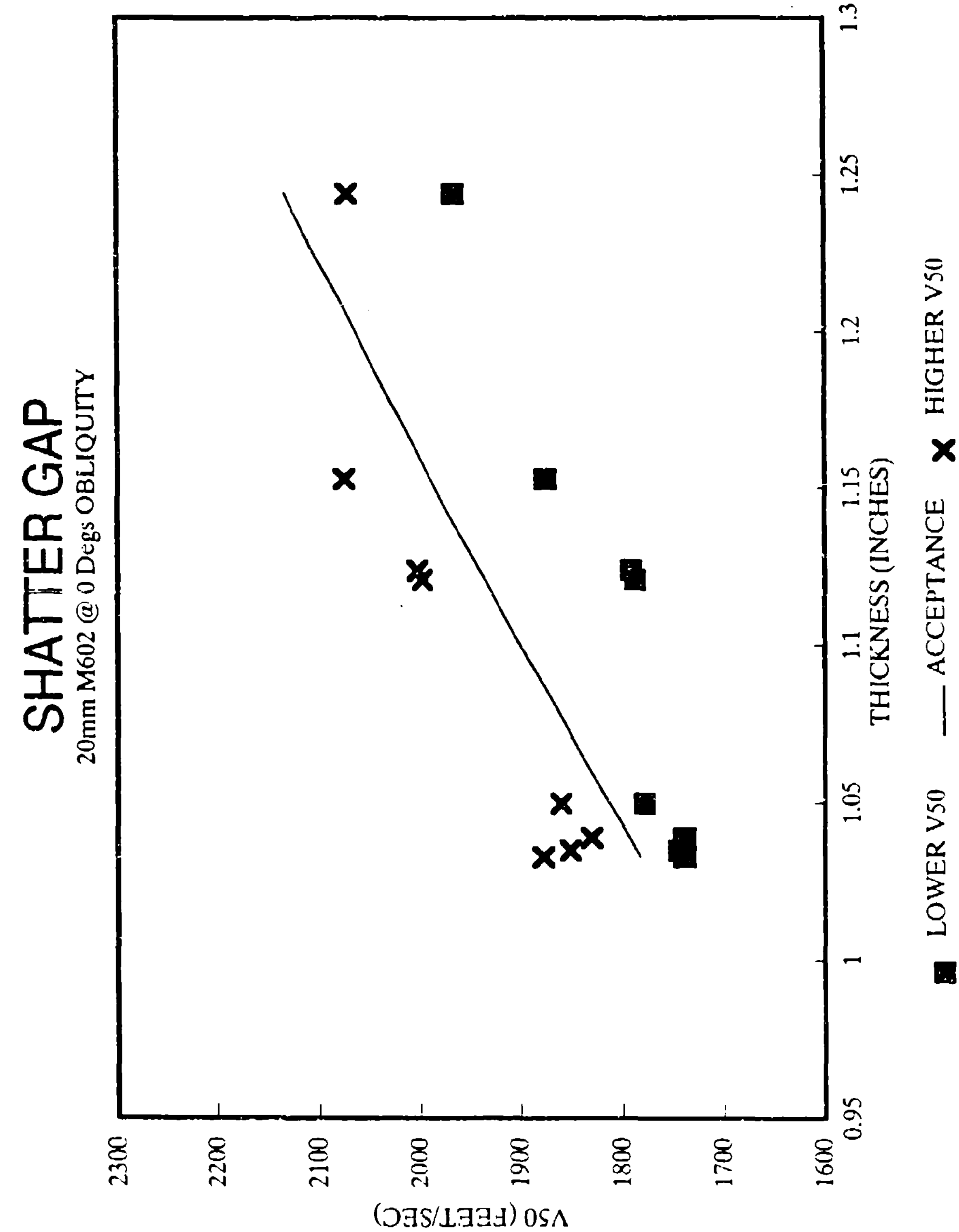

SHATTER GAP
20mm M602 @ 0 Degs OBLIQUITY
V50 (FEET/SEC)
2300
2200
2100
2000
1900
1800
1700
1600
0.95
1
1.05
1.1
1.15
1.2
1.25
1.3
THICKNESS (INCHES)
LOWER V50
ACCEPTANCE
HIGHER V50

Figure 3

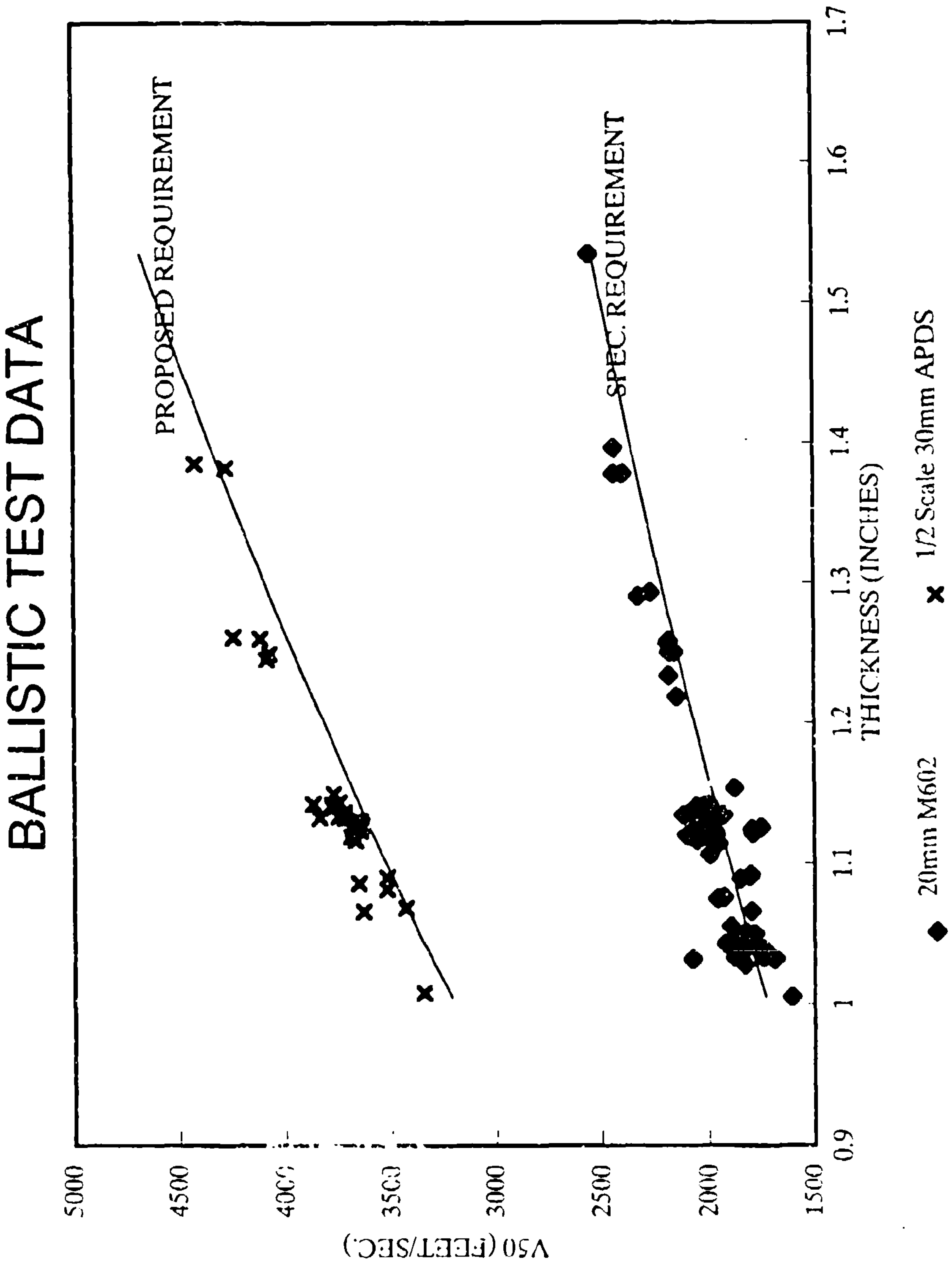
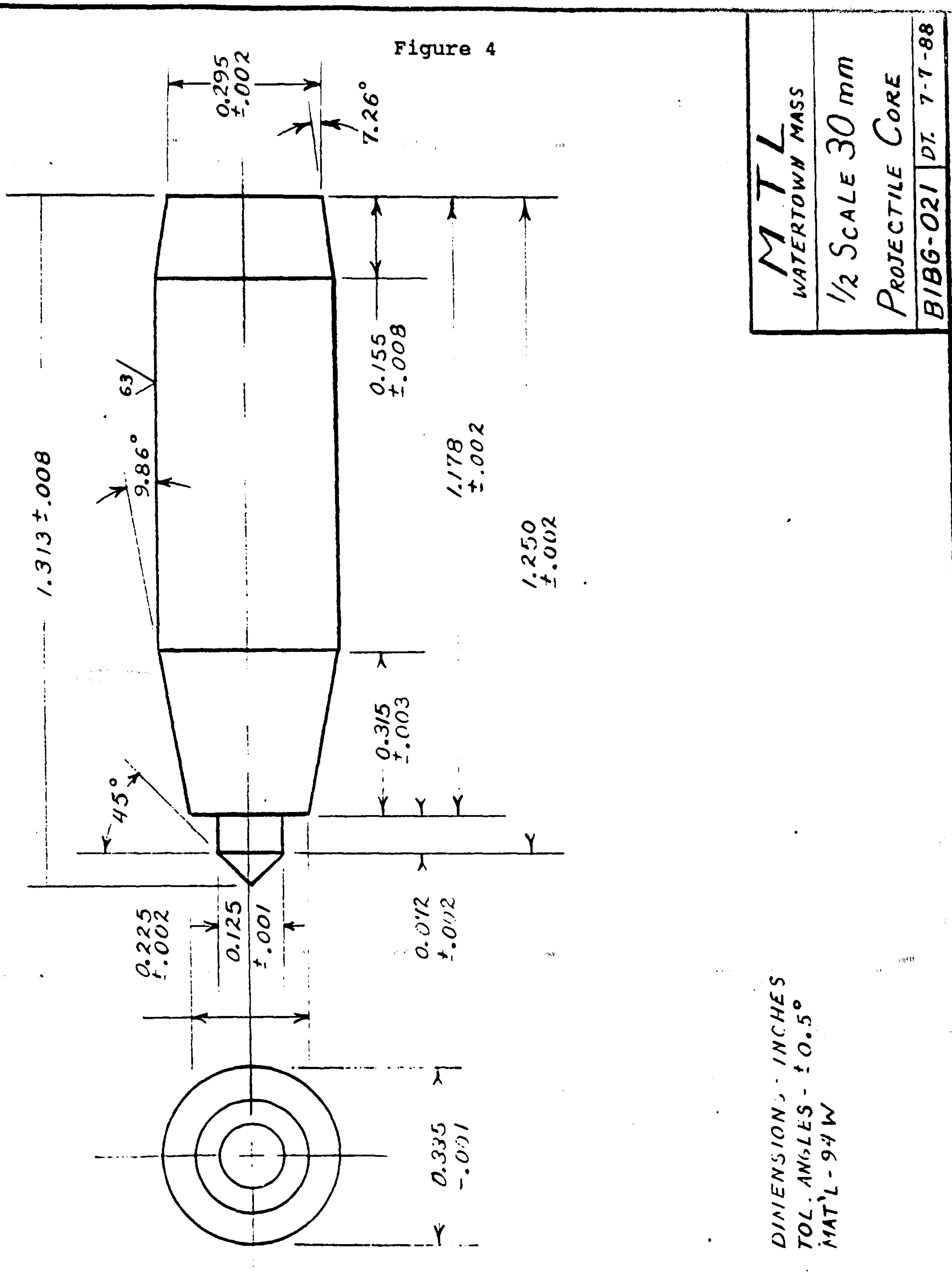

BALLISTIC TEST DATA
PROPOSED REQUIREMENT
SPEC. REQUIREMENT
V50 (FEET/SEC.)
5000
4500
4000
3500
3000
2500
2000
1500
0.9
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
THICKNESS (INCHES)
20mm M602
1/2 Scale 30mm APDS

Figure 4



MTL
WATERTOWN MASS
1/2 SCALE 30 mm
PROJECTILE CORE
B1BG-021
DT. 7-7-88
0.295 ±.002
7.26°
0.155 ±.008
63
9.86°
1.313 ±.008
1.178 ±.002
1.250 ±.002
0.315 ±.003
45°
0.225 ±.002
0.125 ±.001
0.012 ±.002
0.335 -.001
DIMENSIONS - INCHES
TOL. ANGLES - ±0.5°
MAT'L - 94W

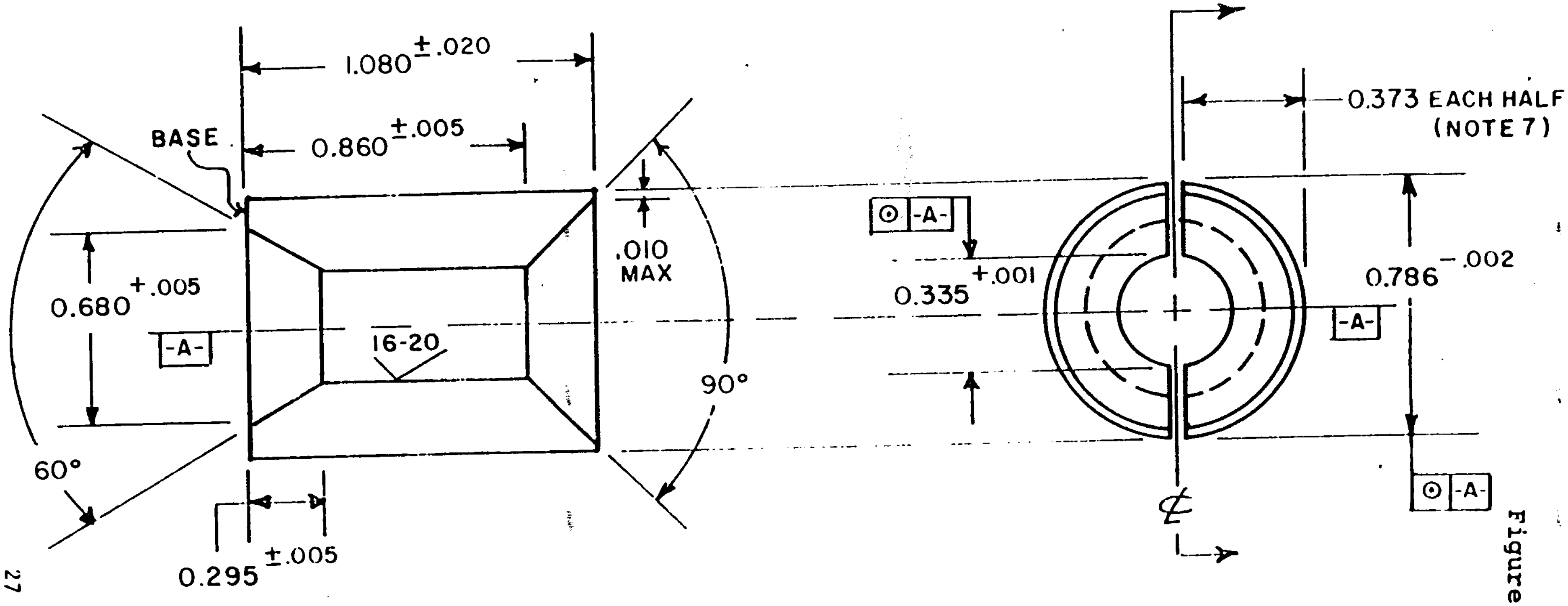


Figure 5

NOTES:

1. MAT'L–NYLON 6/6 (POLYPENCO 101 OR EQUIV.)
2. SAW CUT ALONG ℄ AFTER MACHINING (MAX KERF=0.040")
3. BASE PERPENDICULAR TO -A- W/IN 0.002"
4. CONCENTRICITY WITH -A- ∓ 0.001"
5. ANGLE TOLERANCE = ±1°
6 DEBURR ID SURFACES (0.335 D)
7. 0.373" DIMENSION ASSUMES SAW KERF=0.040"
EACH HALF MUST BE ±0.001" IN FLATNESS AND MEET
ASSEMBLY DIMENSION OF 0.786" WITH 0.335" ROD INSTALLED.

ENG.	20mm SABOT (1/2 SCALE 30 mm PENETRATOR)
SUBM.	ARMY RESEARCH LABORATORY
APP.	*BALLISTIC IMPACT BEHAVIOR GROUP*
DATE 6-22-94	BIBG-022A

APPENDIX A

PROCESSING

- Charge make-up for 750 lb. heat.
- Induction melting into ingots.
- ESR two (2) billets, 8" x 8" x 20".
- Slabbing billets to 3" x 16" x 24".
- Rolling slabs into plates (working temperature = 2100°F.

HEAT TREATING

- Normalize at 1700°F for 1 hour then air cool.
- Austenitize at 1550°F for 1 hour then water quench.
- Snap temper at 280°F for 1 hour then air cool.
- Temper at 425°F for 1 hour then air cool.

Note: For plates thicker than 1.1, the time at temperature was increased to 1.25 hours to insure through temperature.

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